Migratory routes of Black Scoter (*Melanitta nigra*) through Southern New Brunswick

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Introduction

The purpose of this study was to develop a protocol for studying migration routes of Black Scoter (*Melanitta nigra*) through southern New Brunswick using radar and acoustic sensors. Recent studies have shown that Black Scoters migrate through the Bay of Fundy both during the day and at night, and that radar is a viable tool that can be used to study these movements. Our aims were twofold; to better understand the times of night and season that nocturnally migrating Scoters pass through the Bay of Fundy and to devise a system to improve counts of sea ducks in an effort to generate indices of Black Scoter migration using radar data paired with land-based counts and acoustic recordings of flight calls.

The Bay of Fundy is a major sea duck migration corridor in spring and funnels a significant proportion of the East Coast populations of Black and Surf Scoter, and Common Eider past Point Lepreau (Bond et al. 2007). Long-tailed Ducks, White-winged Scoters, Greater Scaup, Eastern Harlequins and a number of other species are also known to use this migration route. These species breed in northern Quebec and beyond, and winter along the Canadian and US Atlantic seaboard. Because these species breed in remote, relatively inaccessible locations, population indices are difficult to generate. It is thought that the geography of the Bay of Fundy concentrates most of the eastern population of these species, making sites throughout potentially useful locations for monitoring population change as individuals pass through during migration.

Black Scoter is a species of duck that is commonly encountered off the coast of New Brunswick and Nova Scotia during its spring and fall migrations (Bond et al. 2007). Members of the species breed in northern Quebec and move up the Atlantic coast from their overwintering grounds near North Carolina during late March through to early May each spring (Bordage et al. 1995). The Bay of Fundy is a prominent feature of the migration route, as Black Scoters are annually observed passing through en route to a staging area in the Baie des Chaleurs at the border of New Brunswick and Quebec (Bond et al. 2007).

Near the mouth of the Bay, standardized diurnal counts of migrating Black Scoters have been conducted annually since 1996 (Bond et al. 2007). The counts have been used as an index of population size and in annual population trend assessments. Observers are thought to be able to detect ducks out to a distance of 2-3 km. However, environmental conditions influence visibility, and so the way in which these observations relate to the overall population is unknown. Observations are not possible at night, on foggy or very rainy days. On windy days, low flying ducks may be obscured by waves and throughout, observations may be biased towards birds that are closer to (or even further from) the observer because they are more readily detected. On days with high volumes of birds, it is likely that observers miss some unknown proportion of birds flying by, which introduces potential bias. There is also an implicit assumption of land-based observation that most birds are flying within visual detection of the point, and that the four hour observation period adequately samples the volume of ducks flying past. In other words, there are not days when the bulk of sea ducks fly beyond the visual limits of the observers, or earlier or later than the observation period.

This uncertainty points to a need to assess movements of Scoters at times when observers are not present (e.g. at night) and when observers cannot see (e.g. during times with poor visibility) both to assess the ability of observers to detect distant targets and to supplement these counts to generate better informed population size estimates. Radar and acoustic sensors can be useful tools to detect biological targets under all of the situations, so we initiated this study to assess the potential of radar observations and acoustic recordings to measure scoter migration at different points on the north shore of the Bay of Fundy.

Acoustic recordings are often used in studies of bird migration to generate counts of individuals of a specific species or group of species (Farnsworth 2005). This is a particularly useful technique for species with a unique flight call, such as the Black Scoter (Bordage et al. 1995). Although the frequency with which many bird species call varies with environmental condition (Cochran 1958, Evans and Mellinger 1999, Farnsworth and Russell 2005, Gagnon et al. 2010) and depending on the time of night (e.g. during flight versus migratory landfall; Vleugal 1960, Gauthreaux 1972), some recent studies have shown that counts of flight calls are positively correlated with counts of tracks in radar data (Larkin et al. 2002, Gagnon et al. 2010; note that this varied among sites in Farnsworth et al. 2004).

The use of radar in ornithological studies provides many advantages; data collection can be automated, it provides a consistent and repeatable method, and can potentially observe passerines and ducks alike at further distances compared to a human observer. This means that radar could be used to sample a broader spatial/temporal area compared to a human observer. Furthermore, radar can also be used to sample at night and periods of reduced visibility. Radar also has several limitations; discrimination of targets to species is usually not possible and discrimination of individuals within flocks is difficult. Small marine radars, such as those employed in this study, are ineffective in rain, and target detection is difficult in situations where targets are situated against a highly reflective background, such as waves and water.

Specific to studies of waterfowl movements, radar technologies including Weather Surveillance (WSR-88D), marine radar, and tracking radar can produce particularly informative data during migration and at known wintering areas. Radar observations of birds near off shore wind energy projects have shown that both fall and spring migrating ducks and geese (Desholm and Kahlert 2005) and wintering Common Eiders (Larson and Guillemette 2007) avoid flying around individual wind turbines, even in the presence of decoys (Larson and Guillemette 2007). Randall et al. (2011) combined Doppler weather radar reflectivity data with field surveys to show that wintering dabbling ducks embarked on nightly flights that were spatially and temporally consistent with foraging flight movements. Recently, radar observations combined with weekly aerial surveys were used to quantify the numbers of ducks present at a well known staging area in Illinois, in addition to estimating mean stopover durations during fall migration over eight years (O’Neal et al. 2012). Others have used radar to examine specific flight behaviours including speed, altitude, and orientation: migrating Common Eiders fly with airspeeds of ~24 m/s in fall (Desholm 2003), while Brent Geese fly with greater airspeed in spring (~20 m/s) than in fall (~16 m/s; Green and Alerstam 2000). Reports of flight altitudes are consistent among North America and Europe with most individuals flying within 200-600 m agl (Green and Alerstam 2000; Mabee and Cooper 2004; O’Neal et al. 2010). Despite a large body size weather factors including wind speed and direction and temperature have been shown to impact flight orientations of waterfowl. Like passerines, ducks and geese alike preferentially fly in following wind conditions and avoid flying in strong headwinds (Beason 1980). Finally, O'Neal et al. (2010) use radar observations to show that intensity of waterfowl migration in fall varies among nights.

Recent advances in software have improved the ability of small radar to deal with persistent clutter, and recent studies have shown that metrics of target size to can be used to classify targets to broad species groups (O'Neal et al. 2010; Matkovich 2011). With these advances, radar can be combined with other technologies to comprehensively explore many of the unknowns related to sea duck movements. In particular, precise estimates of numbers of large birds can be generated to assess temporal (nightly and seasonal) variation. Data collected at multiple study sites can be used to assess spatial variation in bird density. Such data can be fed into models that assess impact of industrial development, or can be considered in ecological contexts (e.g. the prevalence of broad front migration).

The primary aim of this study was to develop a protocol to combine information on Black Scoter migration from radar data, acoustic recordings, and standardized ground counts. This combination will enable us to assess land-based monitoring of sea ducks, to count migrating Scoters at night and in periods of reduced visibility, and will allow us to generate indices of Scoter migration from acoustic recordings. The data will be used to better understand nightly and seasonal flight timing through the Bay of Fundy, and will provide a means to study flight behaviours (altitude, speed, and direction).

Study objectives

1. Relate radar counts to standardized ground counts of flying sea ducks to:
    a. determine the radar settings that maximize the detection of passing sea ducks and minimize the background noise that obscures detection of ducks. We focussed on combinations of antenna angle, radar range, tide height, and wind speed.
    b. determine the circumstances where the radar misses targets detected by an observer and when an observer misses targets detected by the radar.
    c. assess whether sea ducks are passing by Point Lepreau at night or early in the morning, prior to the daily initiation of land-based observations.

2. Relate radar counts of flying sea ducks to counts of calls in acoustic recordings to:
    a. develop a method for estimating numbers of Scoters that migrate through the Bay of Fundy using acoustic sensors.
    b. estimate temporal (nightly and seasonal) patterns of movement, and quantify the flight behaviours (direction, speed, and altitude) displayed by flying Scoters.

3. Relate counts of calls to standardized ground counts of flying Scoters to better understand the rate at which individual Scoters call, as well as how this varies at different times of day/night and in different environmental conditions.

Methods

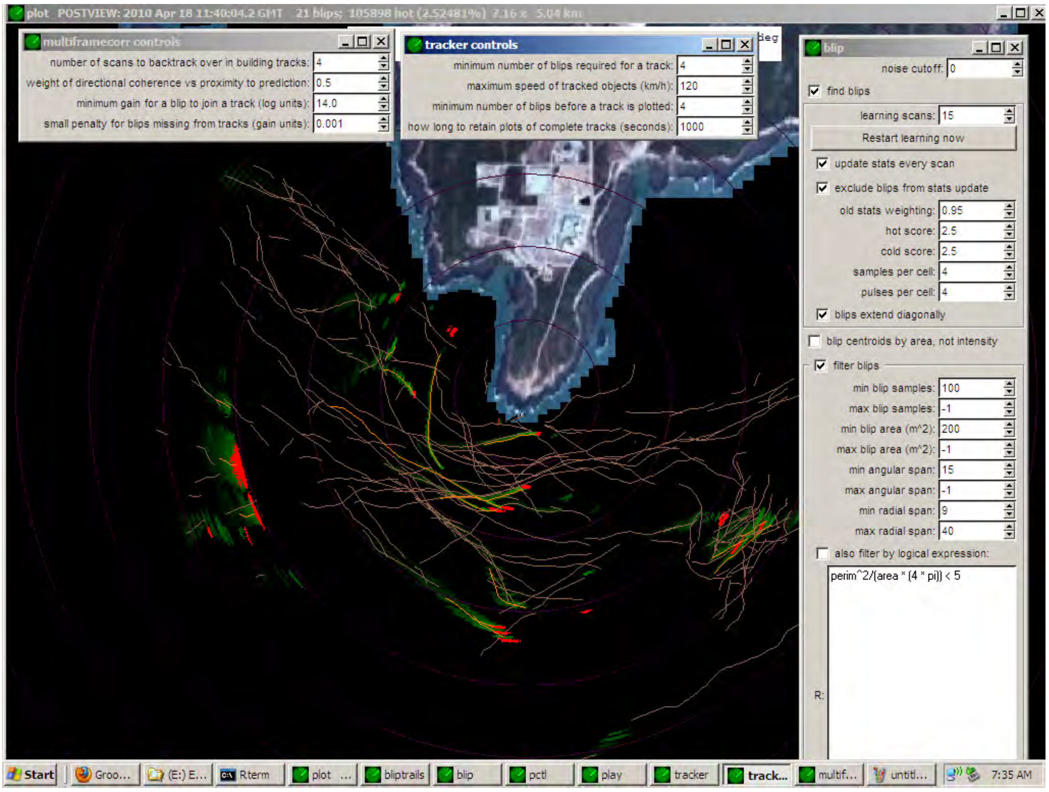
Data collection

The study was conducted at three sites on the north coast of the Bay of Fundy during April 2010 and April 2011. Data were collected using a combination of ground counts, small radar units, and acoustic sensors.

Point Lepreau

In 2010, data were collected at the Point Lepreau Bird Observatory, which is situated at the tip of Point Lepreau and is ~30 km southwest of Saint John, NB (“PL”; 45° 3'30.12"N 66°27'31.59"W). In clear conditions, observers enjoy a field view of ~200 deg with an assumed maximum visibility of ~3 km. The majority of sea ducks wintering at the mouth of the Bay of Fundy are thought to pass by this location (Bond et al. 2007). Standardized land-based counts are conducted by volunteers throughout duck and passerine migration in spring and fall. These daily counts begin within 30 min after sunrise and last for four hours. Counts are conducted in alternating 15 min periods of observation and rest. Birds that are detected passing the point are identified and tallied during observation periods. Tallies by species are later converted to a daily rate. Count data were compiled for both 2010 and 2011 seasons.

Standardized counts were supplemented with 5 min line transect counts to allow for easier comparison between observer counts and radar data for data collected in 2010. Transect counts were conducted during the 15 min rest periods to avoid influencing the standardized data collection. Transect counts were done by the same observer (AKS) using a DFO buoy at a known location (bearing ~180 deg; distance 5.1 km) as a reference point. Counts were recorded using a digital hand-held voice recorder and stopwatch. During each 5 min count, the observer recorded the time, flock size, distance, height above water, flight direction, and the species of every individual or flock passing through the field of view. Distance was categorized as: close (< 1 km), medium (1 – 2.5 km) or far (> 2.5 km). Height above water was estimated to be low (close to the water), medium (a boat’s height above the water) or high (all others). Distance and height estimates were calibrated by using passing fishing boats, which appeared as large, obvious targets on the radar (Figure 1). Weather, sky, and water (tide) conditions were recorded at the beginning of each count period. The observed tidal range during the period of the study was ~6 m.



number of scans to backtrack over in building tracks: 4
weight of directional coherence vs proximity to prediction: 0.5
minimum gain for a blip to join a track (log units): 14.0
small penalty for blips missing from tracks (gain units): 0.001

minimum number of blips required for a track: 4
maximum speed of tracked objects (km/h): 120
minimum number of blips before a track is plotted: 4
how long to retain plots of complete tracks (seconds): 1000

noise cutoff: 0
☑ find blips
learning scans: 15
☑ update stats every scan
☑ exclude blips from stats update
old stats weighting: 0.95
hot score: 2.5
cold score: 2.5
samples per cell: 4
pulses per cell: 4
☑ blips extend diagonally
☐ blip centroids by area, not intensity
☑ filter blips
min blip samples: 100
max blip samples: -1
min blip area (m^2): 200
max blip area (m^2): -1
min angular span: 15
max angular span: -1
min radial span: 9
max radial span: 40
☐ also filter by logical expression:
perim^2/(area * (4 * pi)) < 5

Figure 1. Typical image of radar data processed in program radR. Point Lepreau is at the top of the screen. The black area is water. Radial circles are at 500 m intervals from the radar. Red ‘blips’ are targets and green ‘blips’ are positions of targets from previous scans. Lines are tracks of targets as detected by the automated tracking algorithm in radR. The bulk of tracks move around the tip of the point from the west. The cluster of activity in the lower right hand side of the image is a group of gulls ‘milling about’. The large target ~2 km SW of the radar is a boat.

A Furuno 25 kW X-band radar (Camas, WA) fitted with a parabolic disk antenna (nominal beam width of 4 deg at the half-power points) was operated in front of the observatory on the tip of the point throughout the study. The beam’s bore axis could be set to any angle between 0-90 deg above the horizontal. The radar scanner was mounted level to the ground on a speaker tripod and stabilized with cargo straps. The antenna was ~8 m above sea level at high tide and the console and computer were housed in a portable trailer ~20 m distant.

Radar signals were digitized using a Sigma S6 radar scan converter (Rutter Technologies Inc.) and processed using program radR (version 551; Taylor et al. 2010). The radar was set to transmit at 2100 Hz (short pulse). Radar data were digitized at two different maximum ranges and radial resolutions: 2.56 km range with 2.5 m radial resolution (close range), or 7.68 km range and 7.5 m radial resolution (long range). The antenna angle was set at 3, 4 or 5 deg above the horizontal on any given day. All data were collected in a raw format that included all information returning from the radar signal to allow for more flexibility during post-processing.

At night, the radar was run at a higher angle above the horizontal (5 deg or 10 deg) and data were saved in a partially processed format “.bm” (Taylor et al. 2010). In this format, only data on the time and location in space of all putative biological targets (objects detected by the radar that were moving against the background; “blips”) extracted from the raw data are saved.

Weather data were collected at a weather station at the point. In addition, data on wave height were provided by DFO from a buoy 5.1 km directly S of the point (the same buoy used as a reference in the transect counts).

Technical difficulties prevented the collection of radar data in 2011. An animal of unknown species chewed through the power supply cable at the beginning of the season. However, collection of acoustic data was successful; four acoustic recording devices, Song Meters (model SM2; Wildlife Acoustics Inc., Concord, MA), paired with SMX-NFC weatherproof night flight call microphones (Wildlife Acoustics Inc., Concord, MA) were operated in a diamond formation separated by at least 150 m, which spanned the width of the point.

The Song Meters were programmed to record continuously beginning 30 min before sunset and ending 30 min after sunrise each night. Data were collected at a sample rate of 44.1 kHz with factory default gain and compression settings. Recordings were archived in a series of “.wav” files, each no longer than one hour. Archived data were stored on 32 GB SD flash memory cards. The units were powered using four standard “D” alkaline batteries that were replaced weekly. Microphones were mounted to a 3 foot length of 1½ inch slotted angle iron which was staked in the ground ~8 inches.

Dorchester

In 2011, radar and acoustic data were collected at a Canadian Wildlife Service field station in Johnson Mills, near Dorchester, NB (“Dor”; 45°50'3.35"N 64°30'43.46"W). The radar (description of the unit is as described for Point Lepreau) was mounted ~2 m agl on a custom wooden platform situated at the high water mark on the Bay of Fundy. The radar console and computer were housed in a weatherproof bin ~10 m distant. The radar dish completed a full revolution (360 deg scan) every 2.4 sec. The unit was fit with a customized tilting unit and was programmed to repeatedly tilt the antenna between 3-21 deg in 3 deg increments over 21 min. The radar operated continuously. Large targets were detected up to a maximum range of ~5000 m.

A Sigma S6 radar digitizer was used to digitize the analog radar signals. These digitized signals were subsequently processed and archived using program radR (master version 154054; Taylor et al. 2010). The radars were set to transmit at 2100 Hz and data were digitized at 5.12 km range and 5 m radial resolution. Early in the study period (12-19 April), range and resolution were improperly set to 7.68 km and 7.5 m, respectively. Data on the time and location in space of all blips were stored in blipmovies.

Two Song Meters with night flight call microphones were operated near the radar: ~140 m SE (CWS1) and ~75 m NW (CWS2). The Song Meter settings and data collection procedures were the same as those employed at PL.

Beaubassin

In 2011, radar and acoustic data were collected at the Acadian Ecosystem Research Station at the edge of the Tantramar Marsh (locally referred to as Beaubassin) near Aulac, NB (“BB”; 45°51'4.63"N 64°16'50.35"W). The radar was operated using the same protocol as at Dor, but data were digitized at 5.12 km range and 5 m radial resolution through the entire study period.

Four Song Meters (with night flight call microphones) were operated at varying distances from the radar; ~75 m SE (BB1), ~130 m NW (BB2), ~550 m SE (BB3), and ~375 m NW (BB4). Song Meters were programmed as described above.

Radar data processing

Sources of clutter including rain and reflections from the landscape (such as water and waves) are readily detected by X-Band radar. The presence of these abiotic targets inhibits the ability of the radR software to discriminate biotic targets (e.g. migrating birds). In 2010, automated processing using the existing track finding algorithms in program radR was not possible for data affected by prominent clutter. Unfortunately, many of the blipmovies recorded in this period contained clutter that obscured the passage of birds. Because of the constantly changing tide, pattern of water flow, and wind, the areas of clutter varied considerably, even sometimes within a 5 min count. Since our primary interest was to determine which combination of radar settings would best detect scoters and other targets we elected to proceed in a two-step fashion.

We first subjectively assessed all movies for clutter, and categorized each as high, medium or low. We then modeled the probability that a movie was classified as low clutter by beam angle, wind speed and height of tide to assess which combinations of environmental and radar characteristics produced data with the least clutter. We then selected a subset of movies with minimal clutter that spanned the range of radar parameters that we had initially set. We had anticipated also doing this under a variety of weather conditions (e.g. fog, rain) but we were unable to because weather was generally fair throughout the study; there was only a single day of fog. We viewed this subset of movies, and noted the times and locations where targets crossed a 'virtual' transect in the same location as the real transect. Although this introduces bias (we deliberately were selecting movies when we obtained good radar data), we attempted to view a range of blipmovies were collected at different angles and ranges with few and many targets.

We undertook this manual processing by first extracting a list of target times, sizes and locations (close, medium and far) from the observer record into a spreadsheet. We then viewed each blipmovie a single scan at a time, and noted the range, and approximate 'size' of blips on the screen. Those that appeared to correspond to targets viewed by the observer (e.g. were at the correct range, flew in the same direction and speed, and crossed the transect at the same time) were noted. We also noted targets that were detected by the radar, but apparently missed by the observer.

In 2011, great strides had been made in program radR to automatically eliminate persistent clutter while retaining avian targets. Accordingly, automated processing of the data was possible. Information stored in blipmovies was extracted using program radR and data pertaining to each blip were stored in ".csv" files. As data were extracted, a filter was applied to eliminate blips that were likely returned signals from abiotic targets other than rain (e.g. clouds or waves). Filter parameters were set by watching clips of blipmovies characterized by activity that we were confident was generated by avian targets (1-2 h after sunset when there were straight tracks moving with speeds that were consistent with those observed elsewhere for migrating birds; Schmaljohann et al. 2008).

Simultaneously with data extraction and blip filtering, two new features in program radR were utilized to minimize clutter. To ensure the data were free of rain, we first eliminated any scan that contained more that 1500 valid blips. Persistent clutter generated by reflection from the landscape was eliminated using the 'declutter' plugin. This plugin references site-specific clutter maps that are constructed (by the user) using ~200 scans of radar data containing the repeated clutter. Any returned signals that were consistent with the pattern of clutter contained in the map were automatically eliminated. In a second step, the data were examined for additional, less extreme instances of rain which were manually removed from the data.

A multi-frame correspondence tracking algorithm ("MFC tracker"; 'tracker' plugin) was used to combine blips that were most likely generated by the same targets into tracks. The MFC tracker iterates through scans in a step-wise method to combine blips according to parameters set by the user (gain and alpha).

Gain evaluates the matching between a particular blip in one scan and blips in adjacent scans and uses a probability function to determine which blips were most likely generated by the same target. Alpha is a measure of directional consistency that predicts target location based on velocity at the track endpoint and time elapsed between the track endpoint and new blips. The parameters for the MFC tracker were chosen by watching the same clips that were described above, where gain and alpha were manipulated until the most apparent tracks were ‘found’ by the MFC tracker and until there were relatively few or no tracks that appeared to be generated by non-avian targets. Tracks were formed with gain 18 (logarithmic scale) and alpha 0.6 (1 represents a straight line). Tracks with at least 4 blips and that were moving with airspeed 8 m/s or greater were retained.

As data were extracted, several physical characteristics of the blips were noted including mean and peak intensity, angular span, radial span, area, and perimeter in addition to timestamp and coordinates (in m; the radar represented location 0, 0, 0). Using a series of functions written and implemented in R 2.12.2 (R Development Core Team 2012) these statistics were used to calculate flight altitude (m agl), groundspeed (m/s), bearing (deg), average mean and peak intensity, mean and peak radar cross section, and peak angular span. To calculate heading (deg) and airspeed (m/s; hereafter referred to as flight speed), hourly wind data were obtained from the nearest Environment Canada weather station: Nappan Auto, NS (45°45'34.400" N 64°14'29.200" W; elevation 19.80 m). Concurrent wind speed and direction were estimated for each track by interpolating the wind data to the track data using timestamps. Heading and flight speed were calculated by subtracting the wind vector (wind speed and direction) from the track vector (track bearing and groundspeed). Radar data collected between 30 mins before sunset to 30 mins after sunrise for nights when acoustic data were processed were included in the analyses.

Acoustic data processing

Scoter flight calls were extracted from the archived data using program Raven (pro version 1.3; Bioacoustic Research Program, Cornell Lab of Ornithology, Ithaca, NY). An energy detector that was specialized to identify Scoter sounds was built using time and frequency parameters of known Scoter calls (1250-3750 Hz frequency and 30-500 msec). The detector was applied to each file series (i.e. one series of files per night per microphone) which flagged all sounds that were within the programmed frequency and time bounds as sounds of interest. A standard “.txt” file that contained information on the timing and frequency of each potential sound of interest was generated for each night.

The flagged sounds were manually assessed to generate a final dataset that included the timing of confirmed Scoter calls. The calls were tallied by night and microphone.

Acoustic data collected at Dor were processed for Scoter calls for the entire period of study (15 nights). Following this, data from one microphone over 10 nights (including 5 nights at the beginning of the study period, and 5 nights near the end of the study period) at each of BB and PL were processed for Scoter calls. The subset of nights that were selected for processing at BB and PL were selected based on the number of calls observed at Dor; we attempted to pick a range of nights during which either few or many calls were observed. The remaining data will be processed when more advanced sound classifiers are available.

Analysis of radar data versus count data

Radar data collected at PL in 2010 were subdivided by distance category; several counts were generated, including the total number of targets detected, the number targets that were missed by the radar but seen by the observer, and the number of targets that were seen by the radar but missed by the observer. We fit logistic regression models to assess how each proportion was related to the angle of the radar beam above the horizontal, the distance of the targets, the tide height (including all 2- and 3-way interactions among those terms), as well as wind speed.

Identification of characteristic Scoter targets

A series of technical mishaps allowed for collection of usable data only for a small number of nights in 2010. However, on one of these nights (20/21 April) there were many examples fast-flying targets that moved in a similar fashion Scoters observed during the day. We elected to focus on this single night to investigate characteristics of flying Scoters as observed using radar. This kind of activity occurs on at least some nights at Point Lepreau but we cannot comment on the frequency of these types of flights with the limited data available.

Analysis of radar data versus acoustic data

To generate an index of nocturnal Scoter migration using acoustic data alone, we first needed to generate counts of the numbers of Scoters as observed in radar data. The radars employed in this study sample just a portion of the sky which limits our ability to report an exact estimate of population size, but does allow us to generate an index of population size. Because the highest numbers of calls and tracks were observed at Dor on nights 21/22, 22/23, and 24/25 April (Julian dates 111, 112, and 114 respectively), we used data collected on these nights to identify characteristics to classify tracks that were likely generated by Scoters.

To begin, any track that passed through the radar beam within 5 min of a Scoter call on 21/22, 22/23, and 24/25 April was included in the ‘Scoter’ group. For comparison, an equal number of tracks that were not well matched (i.e. were not observed within 5 min) with a Scoter call were randomly selected and included in the ‘Non-Scoter’ group. There are almost certainly tracks that were not generated by Scoters in the ‘Scoter’ group, just as there are certainly tracks that were generated by Scoters in the ‘Non-Scoter’ group. We separate the data in this way because the tracks that were observed close in timing to a Scoter call are more likely to have been generated by a Scoter than not.

To establish whether there were differences in the characteristics of blips that made up ‘Scoter’ and ‘Non-Scoter’ tracks, we tested for differences in flight speed, peak radar cross section, and peak angular span between groups in a generalized linear model (binomial family). Model selection was performed using a manual, backward term-deletion approach with the least significant parameter estimates ($p > 0.05$) deleted first. Model terms were retained if the overall model deviance was reduced as determined using a likelihood ratio test ($p < 0.05$). Modelling was performed in R 2.12.2 (R Core Development Team 2012).

Deriving population indices from acoustic data

Using the results from the statistical modelling, we generated counts of minimum and maximum counts of tracks in radar data collected at Dor and BB that, according to flight speed and peak radar cross section, were consistent with ‘Scoter’ tracks. At a maximum, any track that was flying with a speed of 16.52 ± 5.76 m/s and that was composed of blips that had 2.92 ± 2.12 m radar cross section may have been a Scoter. Since there was overlap in the flight speed and radar cross sections of ‘Scoters’ and ‘Non-Scoters’, the minimum number of tracks that could have been generated by flying Scoters was the maximum count of ‘Scoter’ tracks minus those whose flight speed or radar cross section fell within the areas of overlap for either parameter.

These counts of ‘Scoter’ tracks were compared to counts of Scoter calls to determine how the counts of calls relate to the numbers of ‘Scoter’ tracks. We use some basic plots and correlation tests to show how among night variation in counts of calls reflects among night variation in numbers of Scoters that fly through BB and Dor.

Variation in Scoter density among sites

Night to night variation in the numbers of Scoters migrating through each study site was examined by assessing variation among sites in the numbers of Scoter calls at PL, Dor, and BB over 7 nights. We tested for correlation among the sites using a series of Pearson's Moment Correlation test, and by examining night-to-night fluctuations in counts using plots of count versus day of year.

Analysis of acoustic data versus count data
Analyses of the relationship between of standardized land-based counts and acoustic data collected at PL conducted in 2011 are ongoing. Our intention is to use these data to further examine the frequency with which Scoters call while actively migrating, and to assess how this changes at different times of the morning and under different environmental conditions.

Potential sources of error

Observer versus radar computer timestamps
Comparison of the ground counts and radar tracks from PL in 2010 is not without potential bias. Times noted by the observer can be approximate, especially during 'busy' periods, but radar times are exact so there is some subjectivity assigning particular radar targets to observed targets. However, if the 'radar observer' was blind to the 'real observer's' notes, then linking sets of observations post-hoc would have been very challenging, because times and locations are not exact. Our aim was to provide an overall assessment of the probabilities of the radar both missing and detecting targets seen and not seen by the observer (respectively) under varying conditions, so the level of subjectivity was thought to be acceptable.

Song Meter versus radar computer timestamps
Comparison of the Song Meter and radar computer clocks showed that one or both drifted throughout the study. By plotting the difference in time between the clocks through time we were able to correct the timestamps assigned to the Scoter calls according to the computer time to the best of our ability.

Track flight speed versus groundspeed
In the analysis that aims to identify characteristics of 'Scoter' tracks versus other targets in data collected at Dor, we focus on differences in groundspeed and bearing corrected for impact of wind speed and direction (i.e. airspeed, or flight speed, and heading). Our desire was to remove bias (both positive and negative) introduced by wind conditions. By removing the wind vector we made the implicit assumption that the tracks completely corrected for wind drift.

Tallies of Scoter calls versus tallies of 'Scoter' tracks
It is impossible to translate the number of Scoter calls into a definitive count of either the total number of individual Scoters that flew through the range of the Song Meter microphones or the number of calling Scoters without directly observing the birds. Therefore, the counts of Scoter calls may represent one of several scenarios:

1. The counts represent the actual number of calling Scoters.
2. Individual Scoters call multiple times.
3. Only some individuals call.

Regardless of how the number of calls per night relates to the number of individual Scoters, these counts represent some unknown proportion or index of the total number of Scoters that fly through an area. Acknowledging this, we attempted to use the data to, conservatively, discuss the spatial variation in flying Scoters.

Results

Data collection at Point Lepreau

A total of 93 5 min line transect counts and associated movies were made between 14-30 April, 2010 at PL. On 11 days radar data was acquired with a maximum range of 2.56 km (and 2.5 m resolution) and ~60 5 min movies and associated counts were obtained. On 5 days the radar was run with a maximum range of 7.68 km (and 7.5 m resolution) and 33 5 min movies and associated counts were obtained.

Across all transects, 1482 individual birds or flocks, comprising 6266 individuals were observed. These were classified into 5 species groups: Eider, Loon, Scoter, unknown, and other. A small number of other species were observed rarely (5 or fewer observations) and were ignored.

Weather conditions varied little through the 2010 observation period, providing little opportunity for assessing the utility of radar with variation in weather conditions. Most days were clear with a visibility of 38 km (Grand Manan Island was visible from the Observatory). Visibility was limited on one day due to fog and there was light rain on another. Tide height ranged from 0.5-6.9 m through the period and wind speed ranged from 0.0-20.8 mph (0-5 Beaufort scale). Temperature ranged from 0.2°C-13.4°C.

We obtained usable overnight radar data on 5 nights. There was considerable passerine migration (small, slow targets were flying N over the point without changing direction at the shore) on one night and on another, 20/21 April, there was evidence that large flocks of sea duck targets were passing the point (fast targets were flying with flight speeds >16 m/s and were oriented NE parallel to the shore).

Song Meters PL1, PL2, PL3, and PL4 collected data for 15 nights between12/13-27/28 April 2011. Data from one Song Meter (10 nights) are presented here, where the number of calls detected per night ranged from 0-101 (Table 1).

Data collection at Dorchester

Radar data and acoustic data collected between12/13-27/28 April. Song Meters operated each night, and a varying number of Scoter calls were identified among them (0-177; Table 1). Radar data were available for 13 nights, and 2005 total birds were detected (Table 2).

Data collection at Beaubassin

Radar data and acoustic data were collected between12/13-27/28 April, 2011. Data collected using one Song Meter over 11 nights are presented here. There were no data available on 22/23 April for BB2 and so data from BB1 were processed for this night only. The number of Scoter calls varied considerably among nights, ranging from 0-123 (Table 1). There were 845 birds observed in 13 nights of available radar data (Table 2).

Table 1. A summary of acoustic data collected during April 2011. For each night in the period that represents peak Scoter migration (12/13-27/28 April), counts of Scoter calls are given for each microphone at three sites in New Brunswick (Dor = Dorchester, BB = Beaubassin, and PL = Point Lepreau). Julian date is specified in brackets in the night column. NA indicates that no data were available and DNP indicates that data have not yet been processed. Data were not available for Song Meter BB2 on 22/23 April and so the data recorded using Song Meter BB1 were used instead.

	Dorchester		Beaubassin	Point Lepreau
Night	CWS1	CWS2	BB2	PL2
12/13 April (102)	54	94	123	0
13/14 April (103)	0	0	1	0
14/15 April (104)	45	64	10	10
15/16 April (105)	11	9	0	40
16/17 April (106)	0	0	0	0
17/18 April (107)	16	16	DNP	DNP
18/19 April (108)	12	0	DNP	DNP
19/20 April (109)	69	88	8	NA
20/21 April (110)	0	0	DNP	DNP
21/22 April (111)	59	100	DNP	DNP
22/23 April (112)	21	29	NA (0)	35
23/24 April (113)	0	0	0	0
24/25 April (114)	177	132	0	0
25/26 April (115)	2	0	0	101
26/27 April (116)	0	0	0	31
27/28 April (117)	0	0	DNP	DNP

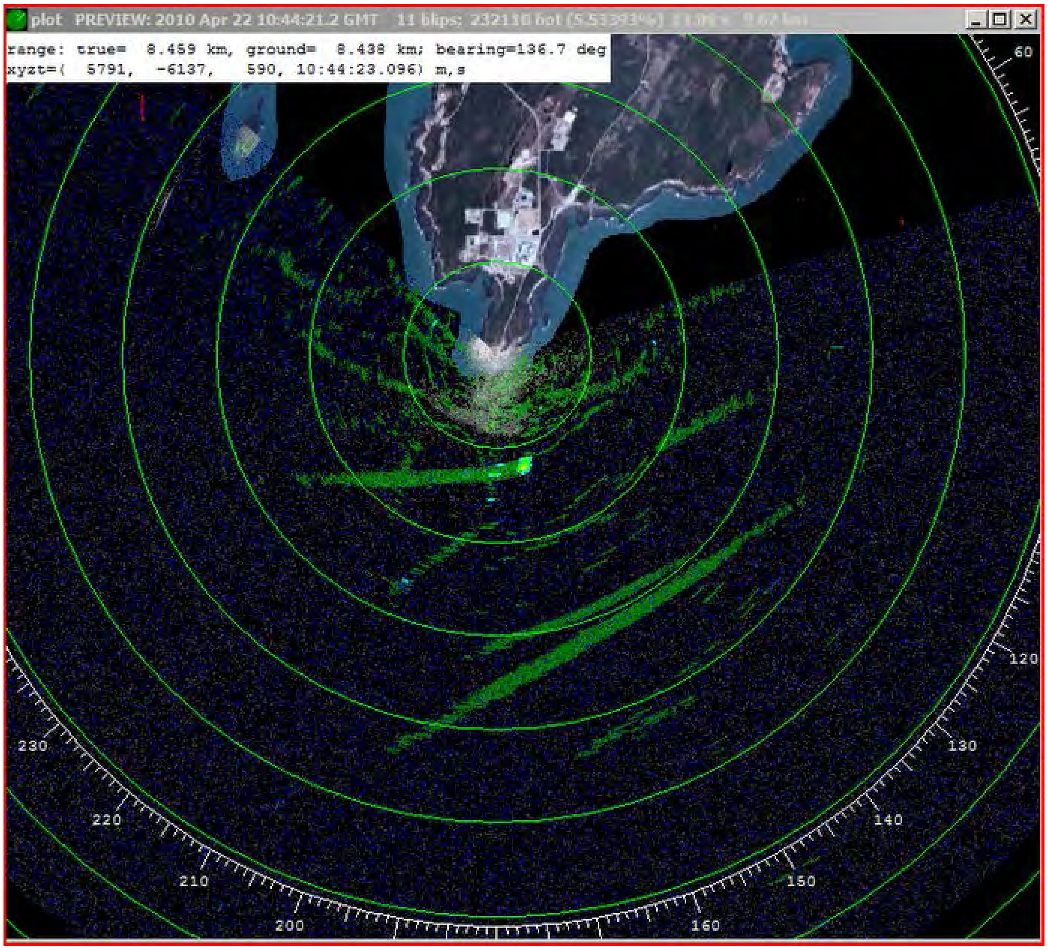
Table 2. A summary of radar data collected during April, 2011. For each night in the period that represents peak Scoter migration (12/13-27/28 April), radar counts of tracks that were generated by any bird species (i.e. all tracks with flight speed >8 m/s) are given for each site (Dor = Dorchester and BB = Beaubassin). Refined radar counts represent counts of 'Scoter' tracks. These tracks were moving with flight speed 16.52 ± 5.76 m/s and were made up of blips with log-transformed peak radar cross section 2.92 ± 2.12 m. The notes section details information on instances of rain and explains why data were not available on some nights. NA indicates that no data were available.

Night	Site	Radar count	Refined radar count	Notes
12/13 April	Dor	31	12	
	BB	83	14	
13/14 April	Dor	35	2	Rain in the second part of the night
	BB	25	3	
14/15 April	Dor	NA	NA	Loss of radar signal for most of the night – cause unknown
	BB	16	4	
15/16 April	Dor	19	1	Rain in the middle of the night
	BB	66	16	
16/17 April	Dor	4	0	
	BB	56	14	
17/18 April	Dor	13	0	Instances of rain throughout
	BB	17	1	
18/19 April	Dor	23	7	
	BB	32	8	
19/20 April	Dor	13	0	
	BB	25	0	
20/21 April	Dor	14	1	Instances of rain throughout
	BB	NA	NA	Error in radR that prevented data collection
21/22 April	Dor	115	72	Rain in the first half of the night
	BB	NA	NA	Error in radR that prevented data collection
22/23 April	Dor	244	82	
	BB	68	6	
23/24 April	Dor	NA	NA	Radar stopped spinning early in the night
	BB	149	20	
24/25 April	Dor	801	324	
	BB	92	47	
25/26 April	Dor	490	213	
	BB	7	0	
26/27 April	Dor	128	10	Instances of rain throughout
	BB	21	0	
27/28 April	Dor	75	22	Instances of rain throughout
	BB	71	22	

Clutter assessment

For 72 movies recorded in 2010, we modeled the relationship between clutter and combinations of tide height and antenna angle. Antenna angle was of primary importance; as antenna angle decreased from 5 deg to 3 deg, the amount of clutter increased substantially. There was some evidence for an interaction where the effect of antenna angle on the amount of clutter depended on tide height (p = 0.15).

During this initial scan we also assessed our ability to observe targets at two range cell resolutions. A general inspection of movies where we collected data at a coarser cell resolution showed that, on the 5 days for which we obtained data, most targets were observed within ~2.5 km range, but that some targets were detected out to a maximum distance of 5 km (Figure 2). We can only generally assess the ability of the radar to supplement observations in fog, because there was only a single day of fog during out observation period. On that day, many gull-like targets (moving slowly and variably with curved tracks) were observed at distances up to 2.5 km along with a few obvious duck-like targets (moving fast and straight, with multiple targets together). We can only state that, as with other studies, that the radar is able to detect ducks in fog.



```
range: true=  8.459 km, ground=  8.438 km; bearing=136.7 deg
xyzt=(  5791,  -6137,   590, 10:44:23.096) m,s
```

Figure 2. Image showing radar tracks of duck flocks off Point Lepreau, NB, at 10:44 GMT 22 April 2010. Radial circles show 1 km distances from the radar, which was situated at the tip of the point. Green ‘tracks’ are the locations of targets detected in previous scans. The bright green/yellow ‘blip’ ~1.2 km SSE of the point is a flock of ~20 scoters detected by both the observer and the radar. Two tracks oriented NE/SW that crossed the 3 km circle were not detected by the observer, nor was the track that is tangential to the 4 km line to the SE of the point. The fact that they were detected at a distance, and that they showed a large reflection on the radar image, suggests that they were larger flocks. Their ground speed, ~20 m/s (72 km/h), suggests that they were ducks.

Target assessment
A total of 23 movies were analysed in more detail; an approximately equal number for each range (2.5 km and 7.7 km; Table 3). For each response variable (proportion of targets missed by the radar and proportion of targets missed by the observer) we fit statistical models to assess how the proportions varied with radar beam angle, distance class (close, medium, far), tide height, wind speed, and interactions between angle and distance, and angle and tide height. We did not look for higher-order interactions because of the relative sparseness of the data set. Similarly, although there was graphical evidence for differences in proportions detected by range, we did not include range as a possible explanatory variable since it was confounded with date. That is, we did not run the radar at long-range on a sufficient number of days for us to discriminate between effects of day or range.

Table 3. Number of movies analyzed at each combination of beam angle and range.

	Range	
Beam Angle	2.5 km	7.7 km
3	2	3
4	5	4
5	4	5

The mean total number of targets per movie was 5.7 ± 5.3 (± sd) and ranged from 1 (11 movies) to 22 (1 movie).

Proportion of targets missed by radar
The response was the odds ratio of the count of targets missed by the radar versus those detected by the observer – the proportion of the total targets missed by the radar. The radar missed targets in most 5 min surveys; the mean proportion of targets missed across all movies was 60% and ranged from ~30% to 100% across combinations of distance categories and beam angle.

There was evidence for an interaction between the angle of the beam and both distance and height (Table 4; Figure 3). When targets were close, the radar tended to miss them at low beam angles, but detect them at high angle and when targets were distant. The radar did most poorly at high beam angles, and best at lower angles. In particular, at the highest beam angle (5 deg) the radar only rarely detected any medium or far targets (Figure 3).

The interaction with tide height is a reflection of the fact that the performance of the radar at a given angle depended on the height of the tide; when the tide height was such that the beam was directed too low or too high relative to the targets, detection was poor. Finally, as wind speed increased, the proportion of targets missed by the radar increased. The radar performed most consistently and best with a beam angle of 4 deg.

Table 4. Analysis of deviance table assessing the proportion of targets missed by the radar. The model is a glm with a binomial family. The response is the number of targets missed by the radar vs. the number not missed (e.g. the log(odds) of the radar missing a target).

Term	df	Deviance	p(Chi)
angle	1	1.34	0.27
distance	1	5.5	0.02
tide height	1	0.001	0.99
wind speed	1	13.06	<0.0001
angle:distance	1	10.61	<0.0001
angle:tide height	1	44.54	<0.0001

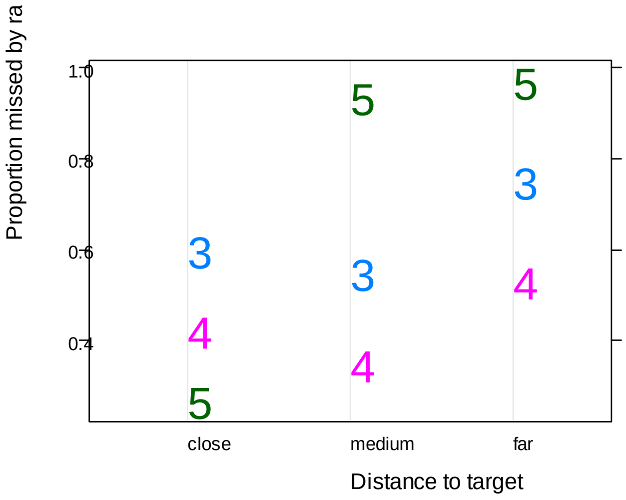


Figure 3. The proportion of targets missed by the radar (as detected by the observer) at three distance classes for each of three beam angles. The points are represented by numbers corresponding to the beam angle.

Proportion of targets missed by the observer

The mean proportion of targets detected by the radar that were missed by the observer was 12%. Across combinations of beam angle and distance categories it ranged from near zero to about 35%. The proportion missed also depended on angle interacting with distance and tide height. There was no evidence for an effect of wind speed. Close targets were most frequently missed by the observer when the beam angle was high, and least frequently when the beam was low, at medium distances (Figure 4).

Table 4. Analysis of deviance table assessing the proportion of targets missed by the observer. The model is a glm with a binomial family. The response is the number of targets missed by the observer vs. the number not missed (e.g. the log(odds) of the observer missing a target).

Term	df	Deviance	p(Chi)
angle	1	4.93	0.03
distance	1	3.02	0.22
tide height	1	2.66	0.1
wind speed	1	2.49	0.11
angle:distance	1	7.67	0.022
angle:tide height	1	7.4	0.007

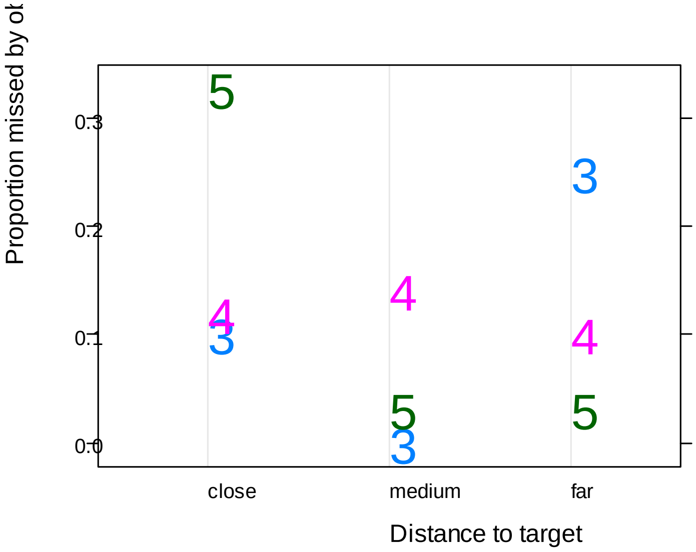


Figure 4. The proportion of targets missed by the observer (as detected by the radar) at three distance classes for each of three beam angles. The points are represented by numbers corresponding to the beam angle.

Analysis of 20/21 April 2010 – characteristics of flying Scoters in radar data

Probable Scoter targets could be classified by speed and bearing; those with speeds >16 m/s (~60 km/h) are not likely passerines and are more likely shorebirds or ducks. Indeed, typical ground speeds observed during the day for known scoters and eiders generally exceeded 16 m/s. Furthermore, most duck-like targets should be readily detected sequentially for a number of scans. We therefore extracted a subset of all of the tracks observed on the night of 20/21 April 2010, keeping only those targets that moved >16 m/s and that were detected 10 or more times by the radar (minimum of 24 sec).

The distribution of tracks by time of night and general bearing is shown in Figure 5. Large numbers of fast moving targets flew past the point between sunset and 3 hours after sunset. Interestingly, between 3 and 4 hours after sunset, a number of targets were observed moving SW (e.g. in the opposite direction) past the point. Just before sunrise (time period 9) a number of targets were observed moving NE at close range to the point. At the peak (1-2 h after sunset) 138 fast targets were detected which puts the rate of passage within the top 10% of rates of passage observed within 5 min transect counts during the day.

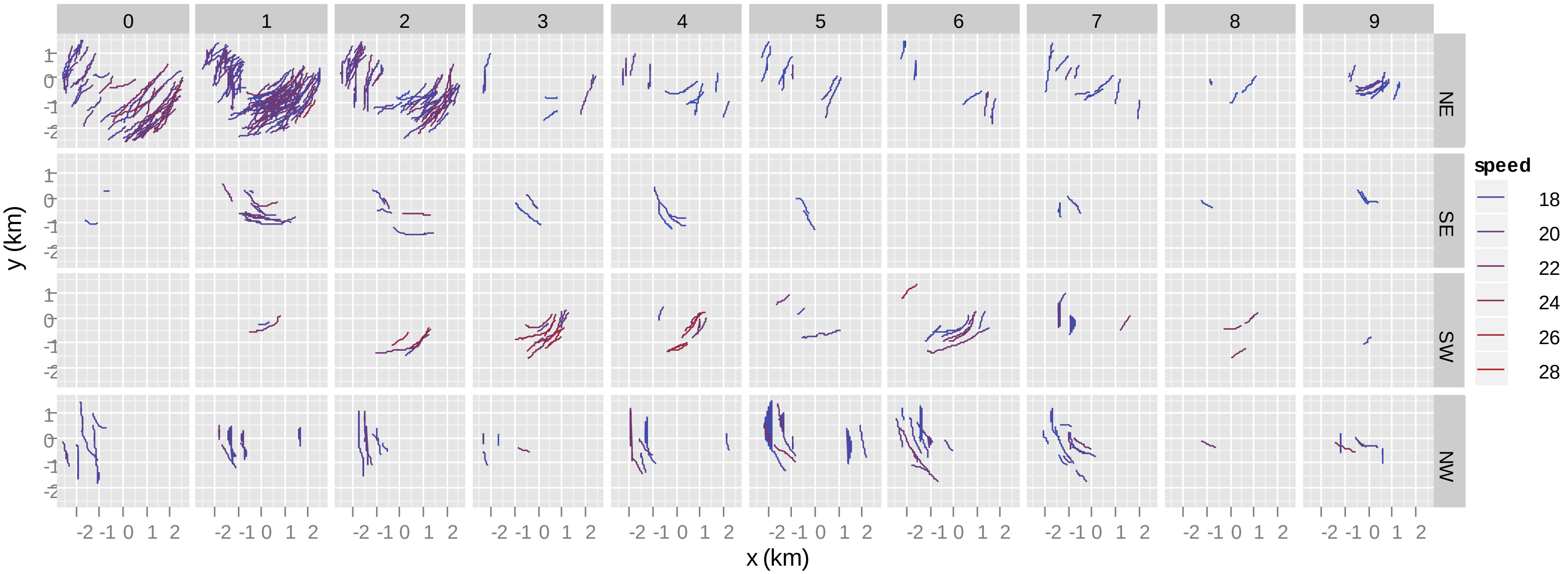


Figure 5. Tracks of ‘fast targets’ (targets moving >16 m/s) at different times of night (hours since sunset) and travelling in three directions (e.g. NE = 0-90 deg) at Point Lepreau, New Brunswick on 20/21 April 2010. Track colour is coded by speed (legend on right side of plot). The average track speed for birds oriented NE that were detected 0-2 h after sunset (inclusive) is 71 ± 1.6 km/h. The total number of targets detected (at least 10 times, with speeds exceeding 16 m/s, and moving NE) in those three periods is 52, 117 and 56, respectively. Note that some of these targets appear to be flying over the point.

Timing of Scoter calls

No Scoter calls were detected before sunset on any night at PL, Dor, or BB. The majority of calls were identified in the two hours after sunset (938 of 1357 total calls). The remaining calls (419) were randomly distributed through the rest of the night, but with only two in the hour before sunrise (these detections occurred simultaneously by CWS1 and CWS2 on 24/25 April). That the calls were concentrated in the first part of the night is consistent with observations of peak nocturnal bird migration during this period. Figure 6 illustrates the timing of calls detected using Song Meters CWS1 and CWS2. Figure 7 illustrates the timing of calls detected using Song Meter BB2 on three of four nights when calls were detected (there was just one call on 13/14 April ~1 h after sunset). Figure 8 illustrates the timing of calls detected using Song Meter PL2 on the five nights that calls were detected.

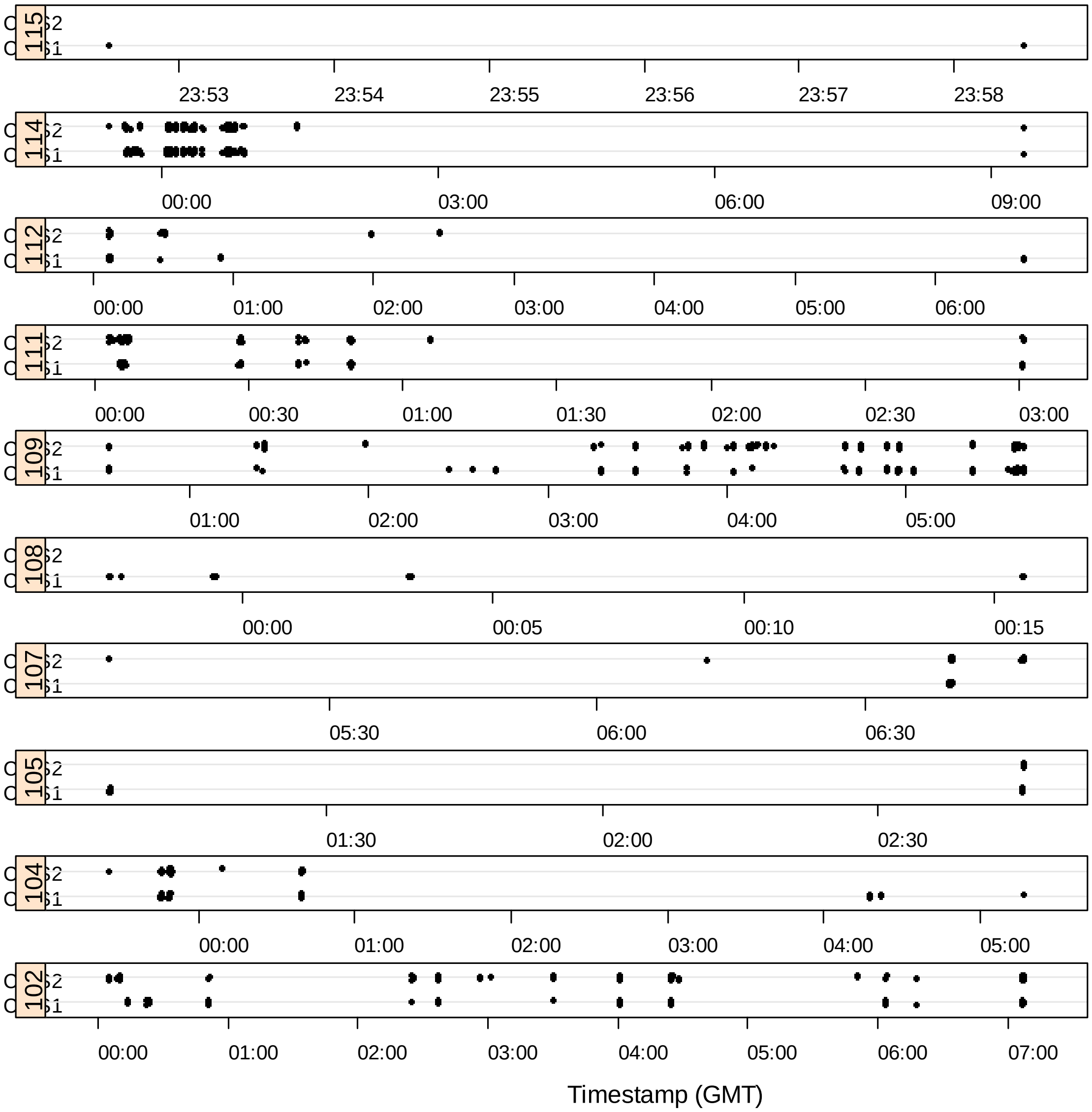


Figure 6. Timing of Scoter calls in GMT (local time + 3 h) as observed in acoustic data collected using two Song Meters at Dorchester, New Brunswick. Data were collected 12/13-27/28 April, 2011 each night beginning 30 min before sunset and ending 30 min after sunrise. The panels organize data by night and Song Meter, which are denoted on the left side of the plot. No Scoter calls were observed on 13/14, 16/17, 20/21, 23/24, 26/27, or 27/28 April (nights 103, 106, 110, 113, 116, and 117 respectively). The points are jittered in the y-axis for clarity.

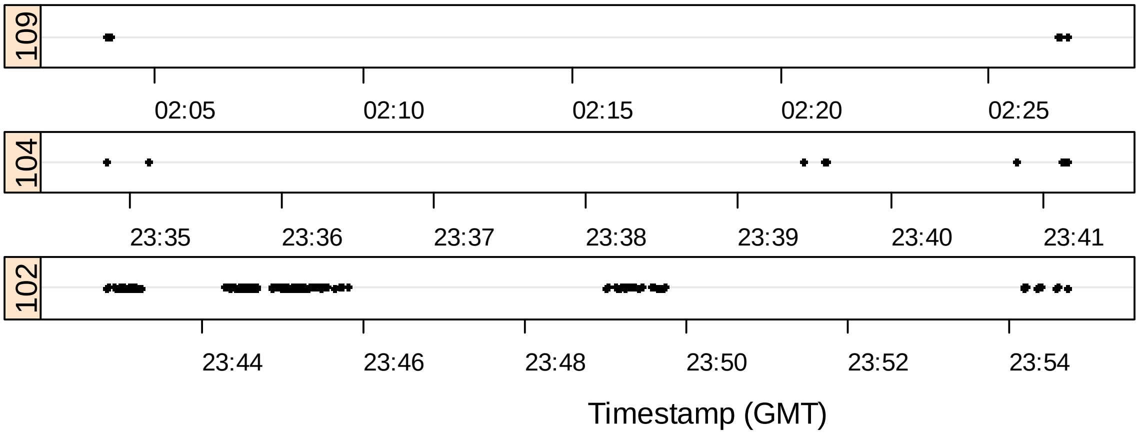


Figure 7. Timing of Scoter calls in GMT (local time + 3 h) as observed in acoustic data collected at Beaubassin, New Brunswick. Data were processed for Scoter calls on 8 nights between 12/13-27/28 April, 2011. The panels organize data by night, which is denoted on the left side of the plot. Just one call was observed on 13/14 April (night 103), and no calls were observed on 15/16, 16/17, 22/23, 23/24, 24/25, 25/26, and 26/27 April (nights 105, 106, 112, 113, 114, 115, and 116 respectively). The points are jittered in the y-axis for clarity.

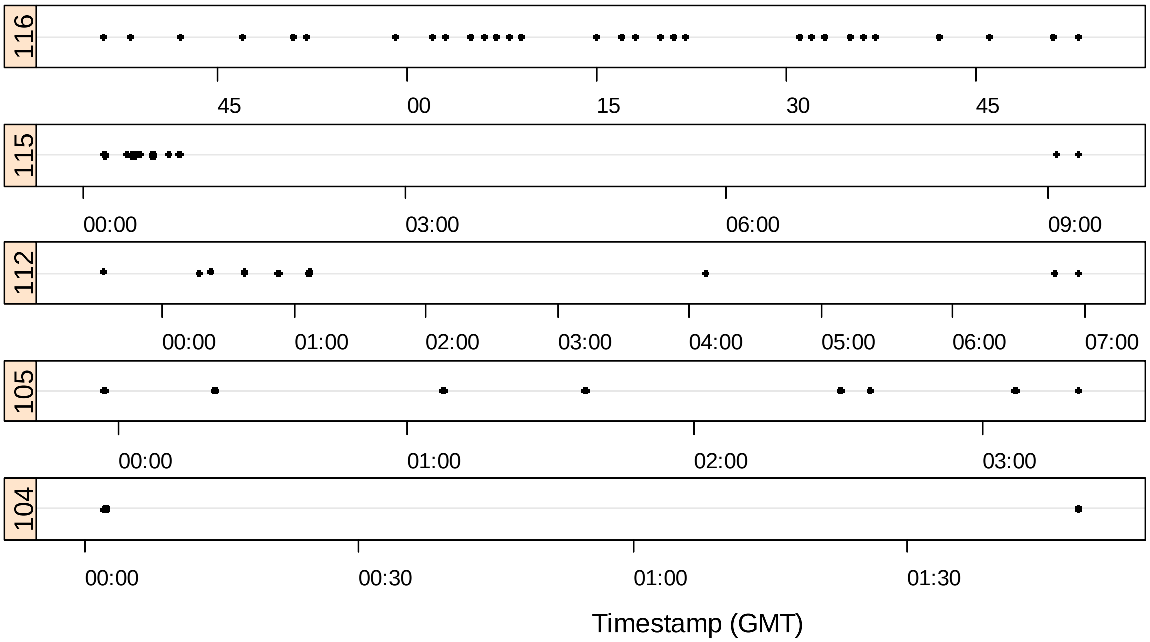


Figure 8. Timing of Scoter calls in GMT (local time + 3 h) as observed in acoustic data collected at Point Lepreau, New Brunswick. Data were processed for Scoter calls on 7 nights between 12/13-27/28 April, 2011. The panels organize data by night, which is denoted on the left side of the plot. No calls were observed on 12/13, 13/14, 16/17, 23/24, and 24/25 April (nights 102, 103, 106, 113, and 114 respectively). The points are jittered in the y-axis for clarity.

Although Song Meters CWS1 and CWS2 were just ~250 m distant, there were unequal numbers of calls observed by each (Table 1). However, when a group of calls was identified in data collected by one, there was a corresponding group of calls in data collected by the other on most nights. Additionally, the night to night fluctuations in the counts of calls were similar between Song Meters (Pearson's Product-Moment Correlation test, $r = 0.905$, $p < 0.05$; Figure 9), which highlights the reliability of data collected using these sensors.

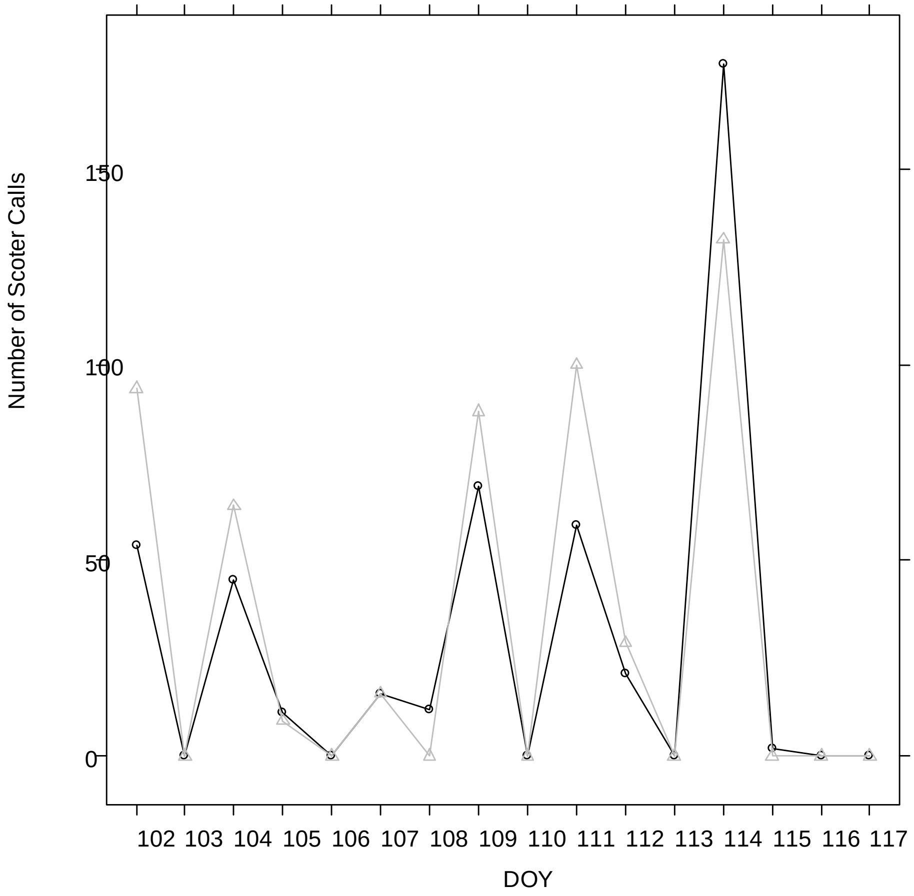


Figure 9. Per night counts of Scoter calls observed in acoustic data collected using two Song Meters at Dorchester, New Brunswick. Data were collected 12/13-27/28 April, 2011. The counts are plotted versus Julian day (DOY). Black circles represent data collected using Song Meter CWS1, and grey triangles represent data collected using Song Meter CWS2. The points are connected with straight lines to highlight variation among nights.

Comparison of Scoter call timing with radar track timing

At least one track was well matched (i.e. was observed within 5 min) of every Scoter call in acoustic data collected at Dor. On night 21/22 April, 159 Scoter calls detected between Song Meters CWS1 and CWS2 were linked to 26 tracks; on night 22/23 April, 50 total calls were linked to 29 tracks; on night 24/25 April, 309 total calls were linked to 171 tracks.

When characteristics of blips that made up tracks in ‘Scoter’ and ‘Non-Scoter’ groups were compared, there was no difference in peak angular span (Table 5). However, ‘Scoter’ tracks tended to fly with greater speed (mean flight speed 16.52 m/s) than ‘Non-Scoter’ tracks (mean flight speed 13.86 m/s) ($p < 0.05$). ‘Scoter’ tracks also tended to be composed of larger blips than blips in ‘Non-Scoter’ tracks, in that they generated greater radar cross sections ($p < 0.05$).

Table 5. Characteristics of tracks that were (‘Scoter’) and were not (‘Non-Scoter’) observed within 5 min of any Scoter call in acoustic data collected at Dorchester, New Brunswick on 21/22, 22/23, and 24/25 April 2011. Given are mean peak angular span (m), mean flight speed (m/s), and mean log-transformed peak radar cross section (m) with one standard deviation.

Group	Peak angular span	Flight speed	Peak radar cross section
‘Non-Scoter’	73.99 ± 17.24	13.86 ± 4.78	1.59 ± 1.97
‘Scoter’	73.27 ± 14.78	16.52 ± 5.76	2.92 ± 2.12

The timing of calls in acoustic data was not well matched with the timing of tracks in radar data at BB for any of the five nights that Scoter calls were detected. Just 2 tracks matched up within 5 min of any Scoter call, and only 6 tracks were observed within 1 h of any Scoter call.

Across 13 nights of radar data collected at Dor, 746 tracks flew with flight speeds within 16.52 ± 5.76 m/s and were composed of blips within 2.92 ± 2.12 m log-transformed peak radar cross section (Table 6). This represents the maximum number of tracks that may have been generated by a flying Scoter. Of these, flight speeds and radar cross sections of 485 tracks overlapped with mean values for ‘Non-Scoter’ tracks, which means that 261 tracks represent the minimum number of tracks that may have been generated by a flying Scoter over the study period. When the same restrictions of peak radar cross section and flight speed were applied to tracks at BB, a maximum of 171 tracks and a minimum of 59 tracks were consistent with ‘Scoter’ tracks.

Table 6. Minimum and maximum counts of tracks that were consistent with the characteristics of ‘Scoter’ tracks (‘Scoter’ min and ‘Scoter’ max, respectively) observed in radar data collected at Dorchester and Beaubassin, New Brunswick. Also given are values that relate counts of Scoter calls to maximum counts of ‘Scoter’ tracks which represent the proportion of tracks that were calling (Calls vs. tracks). Asterisks mark nights that were affected by rain.

	Dorchester			Beaubassin		
Night	‘Scoter’ min	‘Scoter’ max	Calls vs. tracks	‘Scoter’ min	‘Scoter’ max	Calls vs. tracks
12/13 April	4	12	7.83	3	14	8.79
13/14 April*	2	2	0	2	3	0.33
14/15 April	-	-	-	1	4	2.5
15/16 April	1	1	11	9	16	-
16/17 April	0	0	-	5	14	-
17/18 April*	0	0	-	0	1	-
18/19 April	4	7	1.71	5	8	-
19/20 April	0	0	-	0	0	-
20/21 April*	0	1	0	-	-	-
21/22 April*	25	72	1.39	-	-	-
22/23 April	34	82	0.35	2	6	0
23/24 April	-	-	-	5	20	0
24/25 April	103	324	0.55	14	47	0
25/26 April	69	213	0.0094	0	0	-
26/27 April*	4	10	0	0	0	-
27/28 April*	15	22	0	9	22	-

There was considerable variation in the way the number of Scoter calls related to the number of ‘Scoter’ tracks among nights. For data collected at Dor, there were more calls than ‘Scoter’ tracks on 12/13, 15/16, 18/19, and 21/22 April, while there were fewer calls than tracks on three nights (22/23, 24/25, and 25/26 April). Nights 17/18 and 19/20 April represent an interesting case when there were several Scoter calls but no ‘Scoter’ tracks. There is similar variability in data collected at BB. There were more than 8 times more calls than tracks on 12/13 April, and many tracks but no calls on three nights (22/23, 23/24, and 24/25 April). Instances when there were more Scoter calls than ‘Scoter’ tracks must represent times when Scoters were flying in such a way that they were not detected by the radar but were detected by the Song Meters or they are cases when individuals birds called multiple times. The presence of rain on several nights limited our ability to observe tracks of any species and undoubtedly affected the rate at which Scoters called.

Counts of calls were moderately, positively correlated with maximum counts of ‘Scoter’ tracks (Pearson’s Product-Moment Correlation test, $r = 0.58$, $p < 0.05$) at Dor. When the counts were plotted against one another there was no apparent similarity in the way the counts varied among nights early in the study period (except on night 12/13 April; Figure 10). Later in the season, particularly on 18/19, 21/22, 22/23, 24/25 April (nights 108, 111, 112, and 114 respectively), a positive relationship is clearly observed. It seems that on these nights the number of calls can be used to generate indices of Scoter migration at Dor, where relatively high counts of calls per night indicate that large numbers of ‘Scoter’ tracks could be observed. On nights where the numbers of calls exceed the number of ‘Scoter’ tracks we cannot confidently generate the same kind of information without knowing more about the rate at which this species calls under different conditions.

Counts of calls were not correlated with maximum counts of ‘Scoter’ tracks at BB (Pearson’s Product-Moment Correlation test, r = 0.02, p = 0.96). Even when the counts were plotted against one another, the variation in one did not appear to reflect variation in the other (Figure 11).

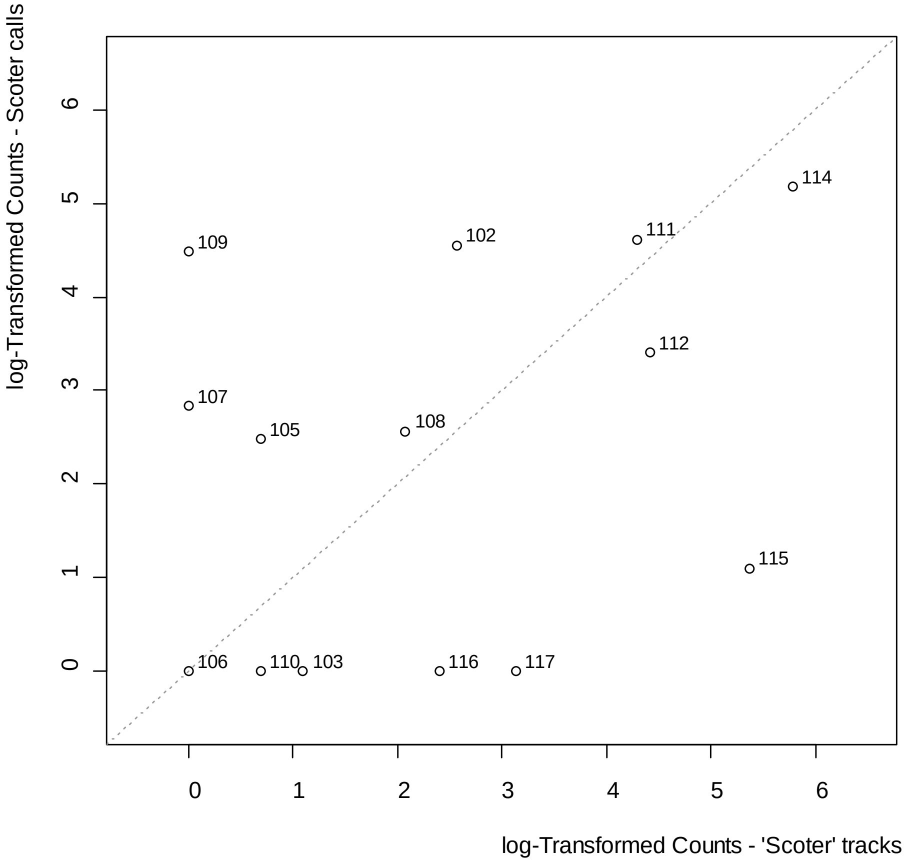


Figure 10. Counts of Scoter calls versus ‘Scoter’ tracks observed in data collected at Dorchester, New Brunswick during April 2011. Each point is identified by Julian day which represents the night that those data were collected. The broken line represents an expected relationship between perfectly correlated counts.

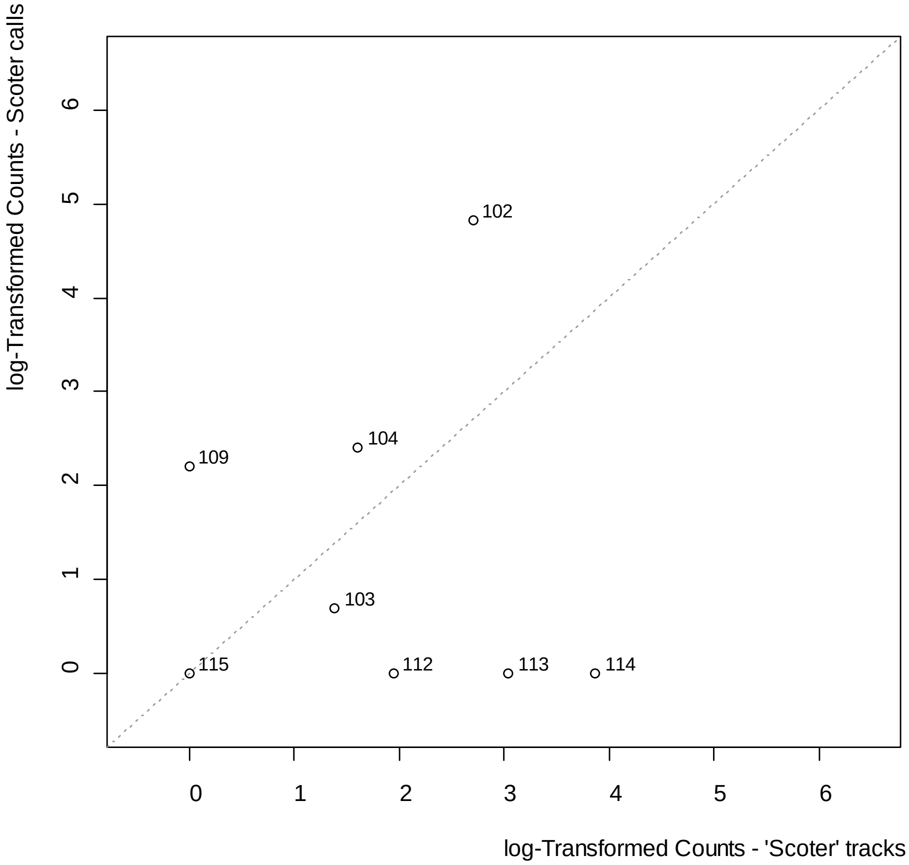


Figure 11. Counts of Scoter calls versus ‘Scoter’ tracks observed in data collected at Beaubassin, New Brunswick during April 2011. Each point is identified by Julian day which represents the night that those data were collected. The broken line represents an expected relationship between perfectly correlated counts.

Flight behaviours of ‘Scoter’ tracks at Dorchester

There were the greatest numbers of ‘Scoter’ tracks on nights in the second half of the study period, between 21/22-25/26 April, 2011 (nights 111, 112, 114, and 115) at Dor (Figure 12). These tracks were further examined to identify behaviours of flying Scoters; counts of ‘Scoter’ tracks remained high throughout the night, but tended to decrease as sunrise approached.

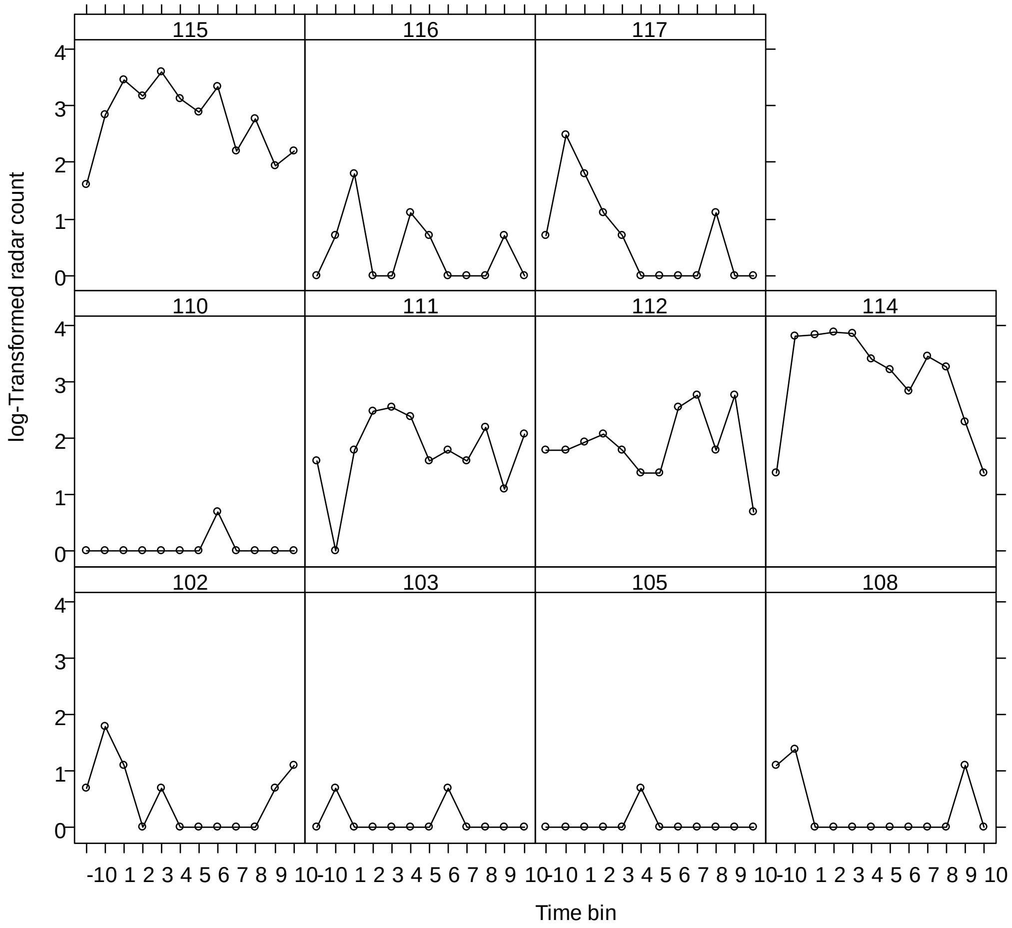


Figure 12. Log-transformed counts of ‘Scoter’ tracks observed in radar data collected at Dorchester, New Brunswick during April 2011. The data are plotted against time of night (separated into 12 time bins) and Julian date.

Further examination of data collected during 21/22-25/26 April showed that mean flight altitude for ‘Scoter’ tracks was ~200 m (Figure 13), mean flight speed was ~16 m/s (Figure 14), and heading ranged primarily between N and NE (Figure 15). The behaviours of tracks observed on nights 21/22 and 22/23 April appeared somewhat different than those of tracks observed on 24/25 and 25/26 April; several individuals were detected flying as high as 750 m, mean flight speed tended to be lower, and headings of tracks were strongly directed NNE on the later nights. On the early nights, the range in altitude was lower, the tracks flew with greater speed, and the headings were not as strongly directed.

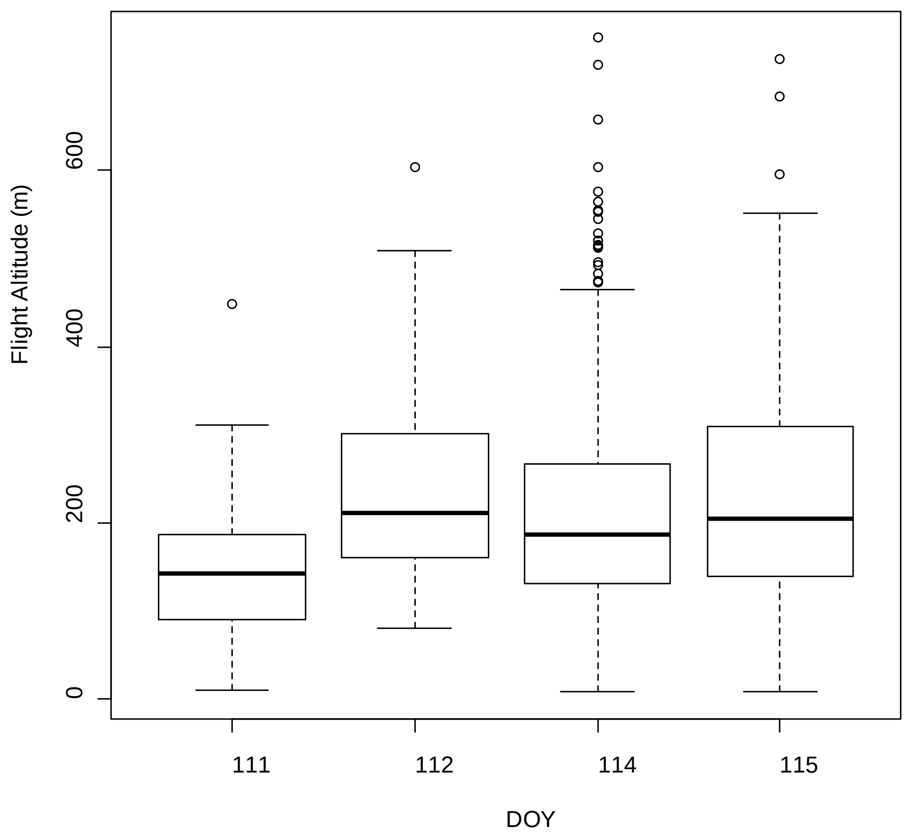


Figure 13. Range in flight altitudes (m) for ‘Scoter’ tracks observed in radar data collected at Dorchester, New Brunswick on 21/22, 22/23, and 24/25 April 2011. The data are plotted by Julian date.

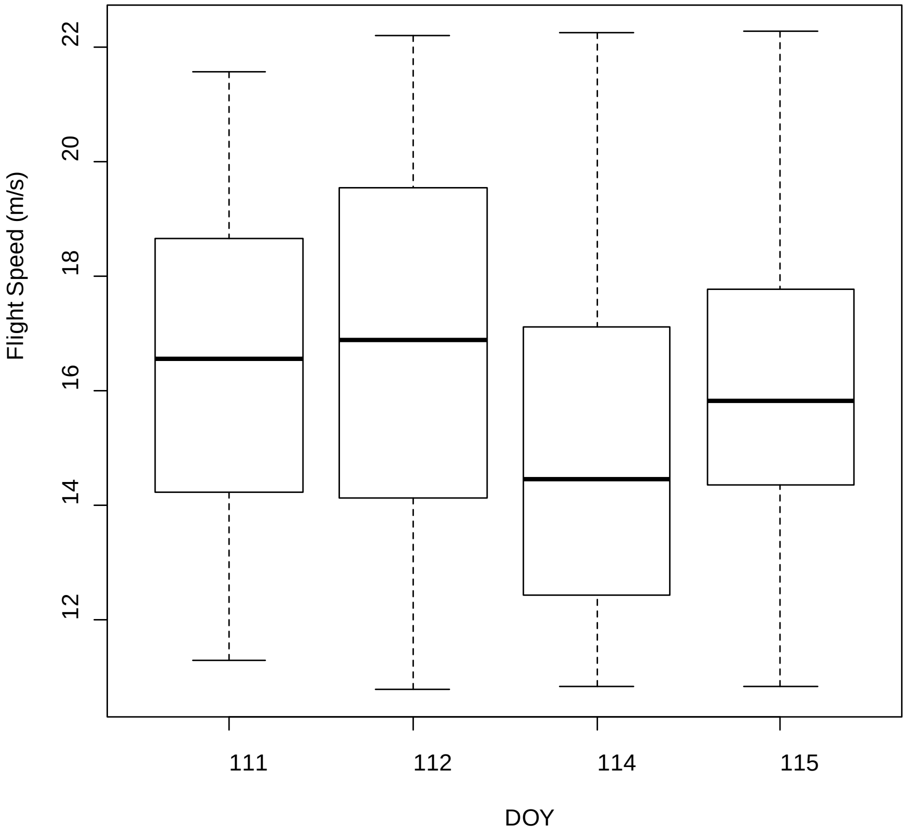


Figure 14. Range in flight speeds (m/s) for ‘Scoter’ tracks observed in radar data collected at Dorchester, New Brunswick on 21/22, 22/23, and 24/25 April 2011. The data are plotted by Julian date.

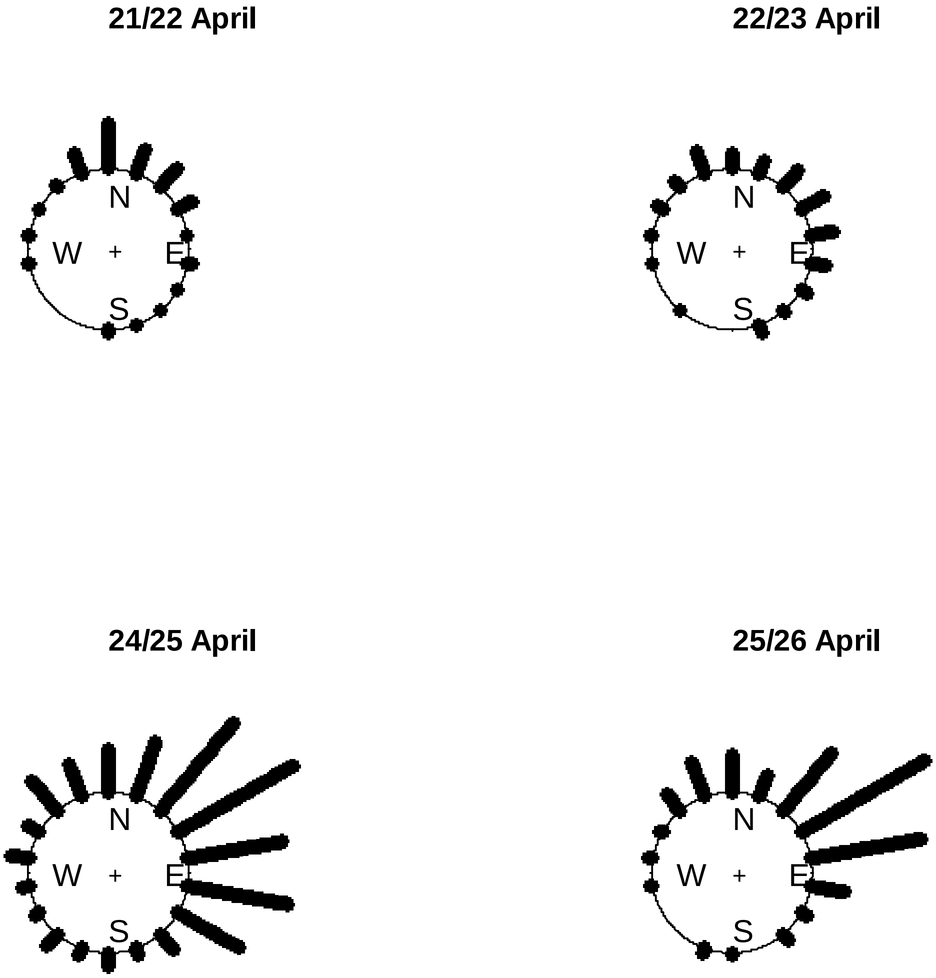


Figure 15. Headings of ‘Scoter’ tracks observed in radar data collected at Dorchester, New Brunswick on 21/22, 22/23, and 24/25 April 2011.

Spatial variation in numbers of migrating Scoters

If you consider that the number of calls must be related to the number of individuals, even without knowing more about the rate at which individual birds call and how that can vary under different conditions, we can compare counts among sites and comment on the spatial variation of Scoters along the Bay of Fundy. There was considerable variation in nightly counts of Scoter calls among three study sites (Pearson’s Moment Correlation Test; all $p > 0.05$), although there is some evidence of correlation between counts at BB and Dor ($r = 0.47$). Plots of the counts through time highlight the among site variation (Figure 16), where the range in counts spanned as much as 0-177 among sites on some nights.

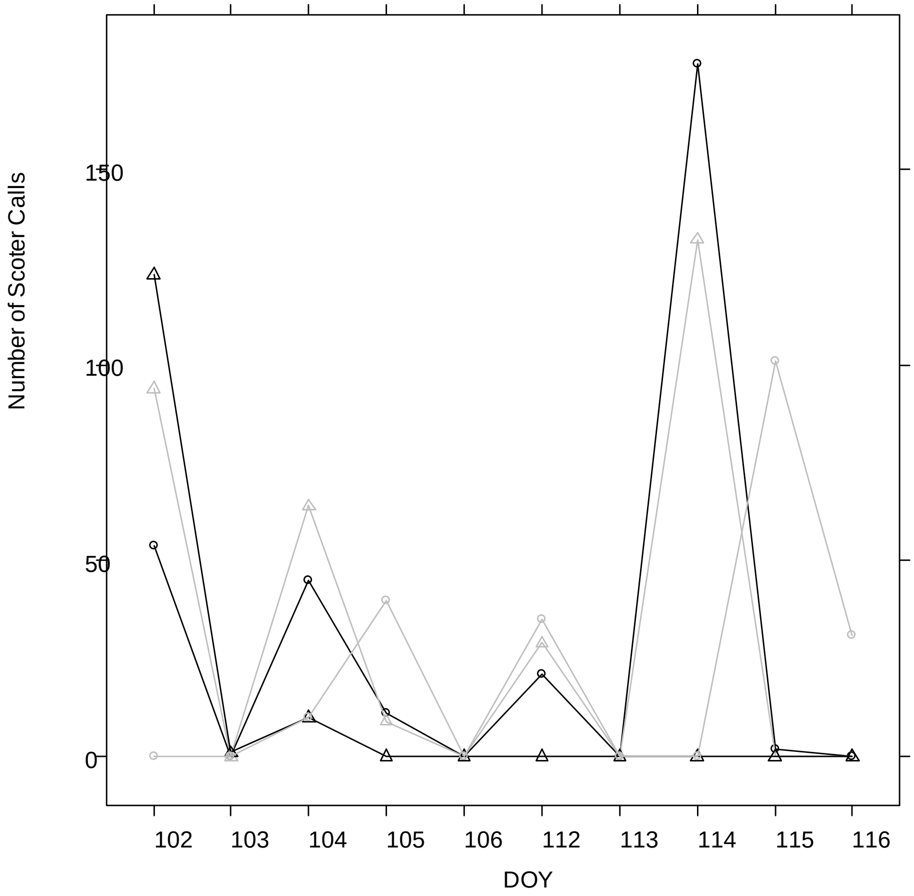


Figure 16. Per night counts of Scoter calls observed in acoustic data collected at three sites in southern New Brunswick. Data are presented for 7 nights in April 2011. The counts are plotted versus Julian day (DOY). Black circles represent data collected using Song Meter CWS1, grey triangles represent data collected using Song Meter CWS2, black triangles represent data collected using Song Meter BB2, grey circles represent data collected using Song Meter PL2. The points are connected to highlight variation among nights.

Discussion

We had reasonable success in achieving two of the three stated objectives. Overall, data collected in 2010 showed that radar observations were useful in detecting distant targets, targets in fog, and targets at night. Obtaining clear (e.g. without clutter) observations of targets at both close and distant ranges simultaneously was difficult. Radar observations can be a useful supplement to human observations, but considerable care needs to be employed in setup and running. Data collected in 2011 showed that counts of Scoter calls can be used to predict relative densities of Scoters aloft in some situations. The flight altitudes, speeds, and directions of ‘Scoter’ tracks observed in radar data should be considered in discussions of impact of industrial development on populations of migratory waterfowl in the Bay of Fundy region.

Analysis of radar data versus count data

The radar missed the lowest proportion of targets with a beam angle of 4 deg and most consistently detected targets missed by the observer at this same angle. Given that clutter tended to increase with lower antenna angles, it seems clear that at the highest angle (5 deg) the radar was missing targets, especially distant ones, and that at the lowest angle (3 deg) targets were being missed because of wave and water interference. Advancements in program radR allow for automated removal of clutter eliminate the need to set the radar antenna angle in a way to 'avoid' clutter. This also improves target detection while allowing the user to position the antenna according to the needs of the study.

Under at least some conditions and antenna angles, the radar detected targets out to ~5 km. These were likely large flocks, and they were flying at speeds consistent with sea ducks (Green and Alerstam 2000; Desholm 2003; O'Neal et al. 2010). There were also flocks that were missed by the human observer. We do not have sufficient data (under optimal conditions) to assess the proportion of time where flocks were present and missed by the human observer, an area that warrants further study. One potential problem is that ideal settings for detecting targets at a distance are different from the settings for detecting targets closer to the point; thus, data collection with radar would have to be done in such a way as to sample different spaces in different ways, in order to develop an overall statistical assessment of the rates of passage.

Varying antenna angle had considerable impact on the utility of individual movies in 2010, and on target detection. This is because a small change in the antenna angle shifts the bottom of the beam up. For example, at a distance of 1.5 km, a shift in the angle of the antenna angle by 1 deg shifts the bottom of the beam by 26 m. Selection of an 'optimal' antenna angle can be a real challenge because of differential behaviours of birds under different conditions (e.g. they fly higher with strong E winds). Although a range of antenna angles could be chosen *a-priori*, a skilled operator would likely have to adjust this for local conditions, and a range of trade-offs (distance etc.) would have to be selected to obtain the maximum amount of useful data on any given day. Alternatively, a newly available automatically tilting unit can be employed to operate on a program to scan through multiple angles as was done in 2011.

Analysis of radar data versus acoustic data

Our attempts to extract relatively complicated trends from acoustic recordings used a simple approach; we explored whether Scoter calls observed at Dorchester and Beaubassin could be linked with tracks of birds observed in radar data according to their timestamps. At Dorchester, the datasets were not only well matched, but this comparison allowed us to identify characteristics that could be used to classify tracks as likely to have been generated by flying Scoters. Per night counts of 'Scoter' tracks were moderately and positively correlated with per night counts of calls, but this appeared to vary across the study period and the number of calls did not consistently predict the number of 'Scoter' tracks. This likely means that the variation in numbers of 'Scoter' tracks that pass through Dorchester cannot alone be predicted by the variation in numbers of calling Scoters.

Among night variation in counts of calls was similar to among night variation in counts of 'Scoter' tracks, though, in the second half of the study period. Although more information about the frequency with which Scoters call and how this varies under different conditions is needed, the similarity in fluctuations of counts suggests that counts of Scoter calls can be interpreted to classify a night as high versus low density migration. More work needs to be done to better understand the relationship between radar and acoustic counts, but that they were highly correlated is a promising step towards using acoustic sensors alone to estimate relative density.

The statistical analysis of characteristics of ‘Scoter’ and ‘Non-Scoter’ tracks revealed that flight speed and radar cross section can be used to differentiate targets generated by birds of different species groups. On average, ‘Scoter’ tracks moved with greater speeds and were comprised of blips with greater cross sections than ‘Non-Scoter’ tracks.

‘Scoter’ tracks were first observed in the hour after sunset nearly every night in the study period and occurred in nearly equal proportions for most of the night. Few ‘Scoter’ tracks were observed in the two hours before sunrise. There were considerably more ‘Scoter’ tracks later in the season compared to early in the season, which may reflect real migration patterns or it may reflect a difference in the way that the radar was set to transmit (the range and resolution settings were changed on 18 April). If this reflects a biological phenomenon, Scoter migration peaked on 24/25 April.

In 2010, the measured groundspeeds of suspected night migrating Scoters were ~20 m/s (72 km/h). That the flight speeds of ‘Scoter’ tracks averaged ~16 m/s in the current study is similar confirms that the group of tracks included in what we termed ‘Scoter’ is made up of Scoters and probably other fast and slower moving birds. The headings of Scoters were primarily NNE, consistent with the orientation of the Atlantic coastline. Given that there is a major staging area in the Baie des Chaleurs (Bordage et al. 1997), these birds may continue on this trajectory to the Northumberland Straight and then move along the east coast of New Brunswick. If this is the case, the spatial distribution of birds should be the same at any two points on the coast (summed across the season) and the population would have an equal chance of being compromised by the presence of industrial development at any point on the northern coast of the Bay. Additionally, the mean flight altitudes of ‘Scoter’ tracks were low, around 200 m. Although several individuals were observed flying as high as 750 m, the majority of birds were < 500 m. The low flight altitude further highlights the fatal risk that migrating Black Scoters would suffer with further industrial development in the Bay of Fundy region.

Spatial patterns of Scoter migration through the Bay of Fundy region

Given that the trajectory of ‘Scoter’ tracks passing through Dorchester was consistent with the main axis of the coastline, we expected to observe similar numbers of ‘Scoter’ tracks at Beaubassin. Across 15 nights, there were consistently more tracks detected at Beaubassin early on, but consistently (and considerably so) more tracks at Dorchester in the second half of the study period. In particular, there are some nights were several hundred tracks (‘Scoter’ and ‘Non-Scoter’ alike) were observed at Dorchester with very few at Beaubassin. This substantial difference could reflect real variation in numbers of birds aloft, yet it seems unlikely that on a clear night in April there were just seven birds, for example, that flew within range of the Beaubassin radar. Rather, it is possible that the radar was not situated to detect the majority of birds that migrated through the site. This point is further supported as numbers of ‘Scoter’ tracks were unrelated to the numbers of Scoter calls observed. Of course it is possible that Scoters were flying in such a way to be detected with the acoustic sensors and not with the radar, but the apparent problem with track detection undermines this theory. For these reasons, there is too much uncertainty associated with counts of tracks at Beaubassin to assess among night variation in migration intensity using radar data.

The acoustic data that were collected do allow for an examination of spatial variation. Numbers of Scoters calls were highly variable among sites and the range in counts varied among nights. This variation could reflect real variation in numbers of migrating Scoters; counts of ‘Scoter’ tracks and Scoter calls were highly correlated at Dorchester which suggests that counts of calls do represent some unknown index of population size. This variation, therefore, indicates that numbers of flying Scoters differed among sites and among nights. Conversely, variation in counts among sites may simply reflect behavioural variation on different nights; the variation in counts may not reflect numbers of individual Scoters but could be a product of variable calling rates (e.g. among individual variation or variation in response to some extrinsic factor such as local weather conditions). In this situation, it would be difficult to assess spatial variation using numbers of calls per night without knowing more about conditions at each site (e.g. tide height, wind speed and direction, presence of rain, and cloud cover). That counts of calls were highly variable among sites do not suggest that among night fluctuations in numbers of flying Scoters were similar across the region.

Summary

- Targets at distance (e.g. > 3 km) are present, and can be detected by radar. Although we cannot conclusively state from this study how frequently such targets are present, we do know that they appear to be missed by human observers.
- It is likely that scoters are flying at night and in the morning prior to the standardized census beginning.
- Counts of Scoter calls and tracks that were likely to have been generated by Scoters targets were positively correlated, but variation in counts of calls alone did not appear to predict variation in counts of tracks.
- Among night fluctuations in counts of calls likely can be used to predict the relative density of Scoter migration (e.g. high versus low), but more information about the frequency with which Scoters call should be incorporated into these estimates.
- ‘Scoter’ tracks flew with mean speeds of ~16 m/s, mean altitudes of ~200 m, and mean headings of NNE.
- The trajectory that ‘Scoters’ follow through the Bay of Fundy suggests that this population reaches the Baie des Chaleurs by following the east coast of New Brunswick but comparison of counts of Scoter calls among three study sites does not support this notion.

Recommendations

- A combination of data collection techniques provides a comprehensive view of Scoter migration through the Bay of Fundy region. Future population assessments should aim to include multiple sources of data, and study sites should be selected to optimally sample flying Scoters.
- Careful placement of radar units is required to ensure optimal target detection given local landscape features.

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